2.5 VIBRATION

2.5.1 Affected Environment

The extended study area is in the core of an urban area with commercial, office, governmental, recreational, and tourism-related land uses. Historic structures and open space are two land use designations of concern for vibration issues in the extended study area.

Changes in levels of ground-borne vibration may result from modifications to the transportation network, which consists of both an on-street vehicular network and the Metrorail subway system. An assessment of vibration and its potential impact on surrounding land uses and structures was performed in response to the changes in traffic flow patterns and vehicle mixes, especially trucks and buses, in the extended study area. This section discusses ground-borne vibration impacts that may have resulted from the security action and subsequent traffic and Metrobus rerouting in the extended study area.

2.5.2 Concepts and Impact Criteria

Ground-borne vibration can be a concern for nearby neighbors of roadway and transit system routes. The effects of ground-borne vibration include movement of the building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. The vibration of floors and walls may cause perceptible vibration, rattling of items such as windows or dishes on shelves, or rumble noise. The rumble noise is the noise radiated from the motion of the room surfaces. This effect is called ground-borne noise.

Noise -

Noise is usually defined as sound that is undesirable because it interferes with speech communication and hearing, or is otherwise annoying (i.e., unwanted sound). Under certain conditions, noise may cause hearing loss, may interfere with human activities at home and work, and, in various ways, may affect people's health and well-being.

When describing sound and its effect on a human population, A-weighted (dBA) sound levels are typically used to account for the response of the human ear. Community noise levels usually change continuously during the day. The equivalent sound level (L_{eq}) is normally used to describe community noise. The L_{eq} is the equivalent steady-state A-weighted sound level that would contain the same acoustical energy as the time-varying A-weighted sound level during the same time interval. The maximum sound level (L_{max}) is the highest instantaneous sound level observed during a single noise measurement interval, regardless of the length of time the sound may persist and whether the noise source is ambient or project related.

Vibration -

Vibration is an oscillatory motion that can be described in terms of displacement, velocity, or acceleration. For a vibrating structural component, such as a building floor, the displacement is the distance that a point on the floor moves away from its static position. The velocity represents the instantaneous speed of the floor movement and acceleration is the rate of change of the speed. The response of humans, buildings, and equipment to vibration is normally described using velocity or acceleration. In this study, velocity is used to describe ground-borne vibration.

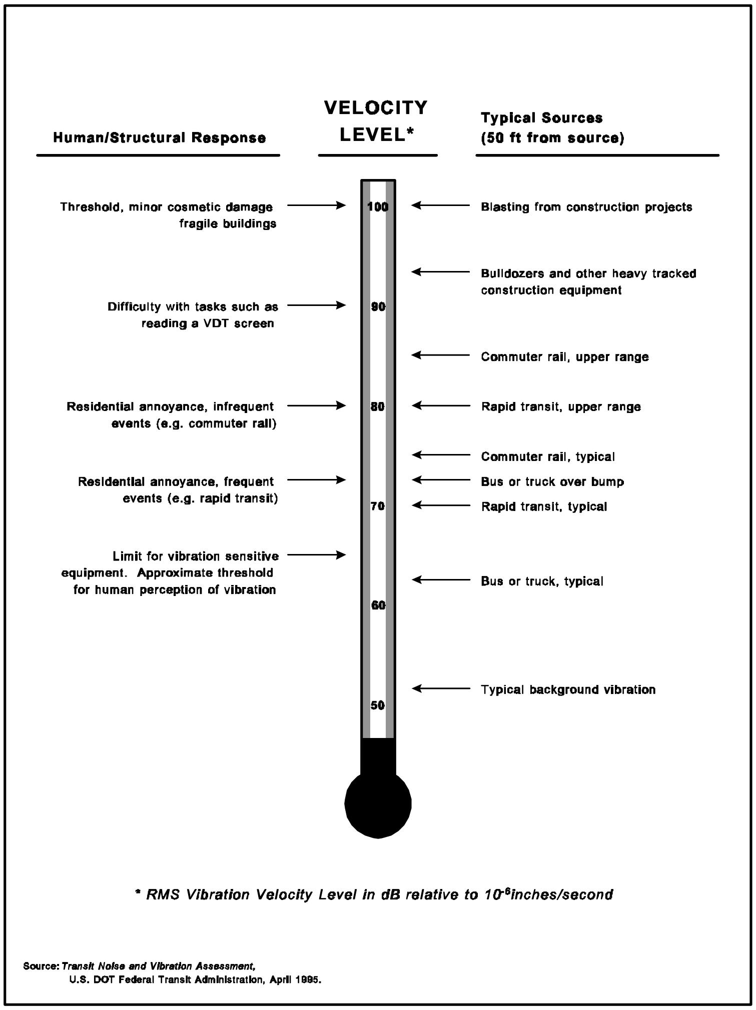
Vibration amplitudes are usually expressed as either peak particle velocity (PPV) or the root mean square (RMS) velocity. The PPV is defined as the maximum instantaneous peak of the vibration signal. The

RMS of a signal is the average of the squared amplitude of the signal. Although PPV is appropriate for evaluating the potential of building damage because it is based on consideration of instantaneous measures, it is not suitable for evaluating human response because it often takes some time for the human body to respond to vibration signals. RMS amplitude is used to evaluate both vibration impacts on buildings and human responses to vibration.

The RMS velocity is normally described in inches per second. Decibel notation acts to compress the range of numbers required to describe vibration. All vibration levels in this study are in decibels and are referenced to one microinch/sec. Figure 2.8 illustrates common vibration sources and the human and structural response to ground-borne vibration. As shown in Figure 2.8, the threshold of perception for humans is approximately 65 dB; however, human response to vibration is not usually significant unless the vibration exceeds 70 dB.

Similar to the noise descriptors, L_{eq} and L_{max} can be used to describe the average vibration and the maximum vibration levels, respectively, observed during a single vibration measurement interval. In addition, exceedance levels are also used where L_{90} exceedance level is the level that is exceeded for 90% of the measured interval; this is generally regarded as the background level. These descriptors assist in the identification of short- and long-duration vibration and provide for better interpretation of measurement results.

There are no Federal Highway Administration (FHWA) standards for vibration. The Federal Transit Administration (FTA) provides ground-borne vibration impact criteria for various types of building uses (USDOT, 1995). Two categories of vibration criteria apply to this security action: they are classified as "human annoyance" and "building damage."



Human Annoyance Criteria -

Table 2-15 presents the criteria for various land use categories as well as the frequency of vibration events. These criteria are related to ground-borne vibration that causes human annoyance or that interferes with the use of vibration-sensitive equipment. The criteria for acceptable ground-borne vibration are expressed, in terms of RMS velocity levels, in dB and are based on the maximum levels for a single event (L_{max}). Human annoyance from vibration events often occurs when the vibration level exceeds the threshold of perception (65 dB) by 10 dB or more. This level is an order of magnitude below the damage threshold for buildings.

All four sensitive receptors on H Street fall under Category 3 with primarily daytime use. Buses and trucks are the major vibration sources within the area. The maximum vibration level of 75 dB will be used as project criteria since buses and trucks occurred more than 70 times per day (i.e., these were “Frequent Events”).

Table 2-15
Ground-borne Vibration Criteria for Human Annoyance

Land Use Category	Ground-borne Vibration Impact Levels (dB referenced to 1 microinch/sec)	
	Frequent[1] Events	**Infrequent[2] Events**
Category 1: Buildings where low ambient vibration is essential for interior operations	65 dB[3]	65 dB[3]
Category 2: Residences and buildings where people normally sleep	72 dB	80 dB
Category 3: Institutional land uses with primarily daytime use	75 dB	83 dB

Source: USDOT, 1995
Notes: 1. "Frequent Events" are defined as more than 70 vibration events per day.
2. "Infrequent Events" are defined as fewer than 70 vibration events per day.
3. This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.

Building Damage Criteria -

There are no FHWA standard building damage criteria related to normal traffic operation. However, the FTA has established a vibration damage threshold criteria of 100 dB for the velocity level of fragile buildings and of 95 dB for the velocity level of extremely fragile historic buildings (USDOT, 1995) for typical construction equipment. The FTA recommends these criteria be used as a damage threshold for the fragile structures located near the right-of-way of a transit project.

The criteria are based on L_{max} for a single event, such as a bus pass by. In addition, the criteria refer to motion at the building ground level and do not consider any allowance for the amplifying or attenuating effects of building structural components, such as may occur in multi-level structures. Since some of the structures within the area (e.g., Decatur House) are considered extremely fragile under this criteria, the L_{max} of 95 dB at the ground level will be used as the building damage criterion.

2.5.3 Measurements

The information contained in this section of the EA is taken from the *H Street Vibration Study*, conducted for the Department of the Treasury by Parsons Engineering Science. The vibration study was performed to determine the potential impact of traffic vibration at historic structures on H Street within the vicinity of Lafayette Square and to present feasible mitigation measures to address potential traffic vibration impact. Due to the emergency nature of the security action, the data collected for this study reflects the conditions after the implementation of the security action. However, the collected data can also be used to estimate the pre-action conditions.

Short-term vibration and noise measurements were conducted from March 18 to March 20, 1997 at four sites along H Street. These sites were selected by the Department of Treasury and identified as sensitive receptors. They include: the Ashburton House at 1525 H Street, the Decatur House at 748 Jackson Place (corner of Jackson Place and H Street), the Dolley Madison House at 721 Madison Place (corner of Madison Place and H Street), and the U.S. Chamber of Commerce Building at 1615 H Street. At each of the sites, measurements were conducted at three locations: outside the building on the sidewalk, inside on the first floor or basement, and inside on the upper floor. In addition, long-term vibration and noise measurements were also conducted at the Ashburton House to provide a typical vibration and noise pattern over a 24-hour period.

Noise and vibration measurements were conducted simultaneously at the outside locations and at each of the inside locations in order to correlate the measured data. For each set of the short-term measurements, data were collected for approximately 10 to 20 minutes to acquire an adequate number of representative bus and truck pass bys. The measurement equipment was set to collect continuous L_{max}, L_{eq}, and statistical level (L_n) measurements and to record at 1-minute intervals for the short- term measurements. For the long-term measurements, the equipment was set to record at 15-minute intervals.

2.5.4 Impacts Analysis

2.5.4.1 Measurement Results

The long-term vibration data are consistent with traffic flow in the area. Higher vibration levels occurred during daytime and evening hours, when the traffic volume is usually higher, while lower vibration occurred during the night (approximately between 2:00 a.m. and 5:00 a.m.) when traffic is usually lower in volume. The traffic volumes began to decrease at around midnight and began to increase again at approximately 5:00 am. Between the hours of 5:00 a.m. and 2:00 a.m. of the next morning, the L_{max} varied between 67 to 77 dB. It was observed and later correlated that L_{max} typically represented vibration generated by buses or trucks traveling over potholes.

The short-term vibration data indicate that the vibration generated by the traffic on H Street exceeded the L_{max} human annoyance criterion of 75 dB for frequent events (more than 70 events per day). This was especially true for the upper floor levels, where L_{max} vibration could be as high as 85 dB. Based on both the long-term and short-term measurements, the building damage criterion would not be exceeded at any location. Detailed data for each measurement site are provided in the *H Street Vibration Study* (Parsons Engineering Science, 1997).

Ashburton House -

Noise and vibration measurements were conducted between 10:45 a.m. and 11:35 a.m. on March 18, 1997 at the Ashburton House. There are two loose manhole covers on manholes that are incorrectly aligned with the road surface in front of the building. Loose manhole covers and poorly aligned manholes can increase vibration when vehicles travel across them.

Review of the measured data indicates that the levels of vibration generated by buses and heavy trucks on H Street is high enough to cause human annoyance inside the building. Data recorded on the first and third floors show that typical vibration levels generated by traffic on H Street are above the threshold of perception. However, vibration levels generated by people walking inside the room are typically higher than those levels generated by traffic on the street. Based upon field observation and the measured data, the rattling of windows at the building is caused by the high levels of low frequency noise generated by buses and heavy trucks as they pass by the structure.

Decatur House -

Measurements at the Decatur House were conducted between 12:30 p.m. and 1:30 p.m. on March 18, 1997. Most of the buses were traveling in the two traffic lanes nearest the building. During the measurement period, there were also tour buses idling on the south side of H Street east of Connecticut Avenue.

High background vibration levels exist in Decatur House, probably due to a building mechanical system. The background vibration levels for both the outside and inside locations are well below the threshold of perception. However, the maximum vibration inside on the third floor is well above the human annoyance criterion. Review of the measured data indicates that there is a strong amplification of vibration from outside to inside due to the building's structure. The maximum vibration levels are primarily due to buses and heavy trucks passing on H Street. Buses and heavy trucks typically generate vibration above L_{max} of 80 dB inside on the third floor. Based on the measured data, these sources generate vibration inside the first floor of the Decatur House of up to an L_{max} of 86 dB.

Noise generated by bus and truck exhaust can be heard inside the Decatur House on the third floor. These sources generate noise levels up to an L_{max} of 94 dBA at the sidewalk level.

A moisture and vibration study was prepared at the Decatur House for the National Trust for Historic Preservation in December of 1994 (NTHP, 1994). The study concluded that the major sources of vibration at the Decatur House were bus and heavy truck traffic through the intersection of H Street and Jackson Place. Because the study was completed in 1994, its data can be used in conjunction with the 1997 measurements to establish the baseline vibration condition.

Dolley Madison House -

Measurements at the Dolley Madison House were conducted between 3:45 p.m. and 4:30 p.m. on March 19, 1997. During the measurement period, most of the buses were traveling in the second traffic lane from the south sidewalk.

The background (L_{90}) vibration levels measured both outside the building on the sidewalk and inside the building in the basement are well below the threshold of perception. The maximum vibration levels for these locations were 75 and 71 dB, respectively. There is no vibration amplification between the sidewalk and the basement. In addition, the maximum vibration levels inside the building in the basement are below the human annoyance criterion. The vibration measured on the third floor is higher than that measured in the basement, due to the amplification by the building's structure. During the measurement period, there were vibration events with the maximum level above L_{max} of 75 dB, the level at which human annoyance can occur.

The noise measured inside the building in the basement was mainly due to the building mechanical system, with occasional loud noise from buses and trucks traveling on H Street.

Chamber of Commerce -

Noise and vibration measurements were conducted between 10:05 a.m. and 11:05 a.m. on March 20, 1997 at the Chamber of Commerce. There are two loose manhole covers, one in the nearest lane and one in the second lane, in front of the Chamber of Commerce building. Loose manhole covers can increase vibration when vehicles travel across them. Most of the buses were in the lane next to the south side curb.

The simultaneous vibration data collected outside the building on the sidewalk and inside the building in the basement indicate background data well below the threshold of perception. The maximum vibration level measured inside the basement was 72 dB, due to a bus traveling in the middle lane on H Street. Inside on the first floor of the building, the maximum vibration level measured was 83 dB.

The noise measured inside the building in the basement was mainly due to the vending machines. Noise from traffic can be heard inside the building at the first floor entrance area; however, people engaged in conversation generally produce higher noise levels.

2.5.4.2 Analysis

Because the rubber tires and suspension systems used on buses and trucks provide vibration isolation, it is unusual for these vehicles to cause excessive ground-borne noise or vibration when operating over smooth pavement. Most vibration problems are related to uneven street pavement due to potholes, bumps, expansion joints, manholes, or other road surface irregularities. An increase of about 10 dB can be expected if there is unusual roughness in a road surface. H Street in the study area can be characterized as having rough pavement.

Review of the measured vibration levels indicates that the maximum vibration levels generated by traffic on H Street range from L_{max} of 70 to 81 dB. These levels are typical of buses and heavy trucks operating over rough pavement. For receptors located along the south side of H Street, the maximum vibration levels are similar to those levels of the pre-action condition. A 5 dB increase in maximum traffic vibration levels can occur for receptors along the north side of H Street as a result of the parking lane removal. Since the new lane is used as a left-turn-only lane, traffic traveling in this lane is normally of a lower volume.

The outside vibration levels generated by traffic on H Street are well below the FTA criteria of 95 dB for structural damage to extremely fragile historic buildings. However, the measured vibration levels are above the threshold of perception and in some cases exceed the FTA criteria for human annoyance. The vibration levels measured inside the sensitive receptors are also well above the threshold of perception and also exceed the human annoyance threshold.

The total traffic volumes on H Street have increased compared to pre-action conditions. The traffic path on H Street in the area has been changed from two directions (east and west) to one direction (east). A parking lane on the north side of H Street was converted to a traffic lane after the security action was implemented.

Although traffic conditions have changed as a result of the security action, the type of vehicles, such as Metro buses and tour buses as well as heavy trucks, would be the same as in the pre-action conditions. Maximum vibration is normally due to a single event such as a bus or a heavy truck traveling by the receptor. Therefore, the pre-action maximum vibration levels due to traffic for receptors located along the south side of H Street (Decatur House and Dolley Madison House) would be similar to that of the measured data. For receptors located along the north side of H Street (Ashburton House and the Chamber of Commerce), the pre-action vibration levels occurring at these receptors would have been lower than that of the measured data because the pre-action parking lane would have provided a buffer zone. Although the maximum vibration levels would not be increased, the number of vibration events would be increased due to the increase in traffic volumes on H Street.

The pre-action vibration measurements conducted for the 1994 report at the Decatur House were measured in terms of PPV. As described in Section 2.5.2, post-action vibration levels were measured using RMS, which is suitable for measuring both building vibration and human annoyance response. PPV is not suitable for measuring human response. In order to provide a comparison of data between the pre- and post-action vibration conditions, a standard 10 dB adjustment from PPV to RMS was used. With this conversion applied, the maximum pre-action vibration levels outside of the Decatur House would have varied from 60 to 81 dB. The post-action maximum vibration levels at Decatur varied from 58 to 74.

The 1994 study also concluded that the vibration amplitude in the third floor of the building was about three times the vibration amplitude at the ground level. This represents an increase of about 10 dB in vibration level. The post-action measurements show an increase of 10-15 dB in the maximum vibration levels between the outside ground level and inside the building on the third floor.

Based on (1) the current analysis, (2) the comparison of the current analysis with the 1994 analysis at the Decatur House, and (3) the composition of the traffic, it can be concluded that existing structures in the area of the security action along H Street were exposed to traffic vibration of similar magnitude before the security action was implemented. The baseline vibration levels would have been below the building damage criterion for extremely fragile buildings. However, occupants in the sensitive receptors would have been exposed to vibration levels exceeding the human annoyance criterion even prior to the action.

2.5.5 Vibration Reduction Recommendations

While the analysis did not identify any major change in vibration levels between the pre- and post-action conditions, it did identify recommendations for consideration by DCDPW that would serve to reduce the vibration annoyance levels from truck and bus traffic along H Street. These are:

- smoothing the surface of the roadway in the blocks adjacent to the historic structures
- replacing the loose manhole covers along the roadway, and
- enforcing existing tour bus parking/idling restrictions on the south side of H Street.